Radon in Dwellings of Papua New Guinea: Observations of a Preliminary Study

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***Abstract*—Restricting exposure to hazardous materials and epidemics is a primary step in reducing health concerns of the public. Radon and its progeny are known potential indoor air pollutants causing higher risk of lung cancer through chronic exposure. There is no known threshold concentration below which radon exposure presents no risk. Even at low concentrations, radon can result in an increase in the risk of lung cancer. We have made a preliminary study on the levels of indoor radon and thoron concentrations in selected populated locations in the city of Lae in Papua New Guinea using both active and passive methods of measurement. The basic source term of indoor radon, the flux from the soil air has also been determined. The overall average indoor activity of radon gas was 13.4 ± 3 Bq m^{-3}, that for thoron was 2.5±1.1 Bq m^{-3} and the annual average inhalation dose was 0.25±0.12 mSv. The radon flux from soil air was found to be 12.7 Bq m^{-2} h^{-1}. The concentrations of radon and thoron progeny and their equilibrium factor were also determined. It is found that the dwellings have lower levels of radon as compared with the dwellings in many other regions of the world.**

***Index Terms*—Radon, thoron, soil radon, inhalation dose.**

I. Introduction

Every earthen material contains primordial radionuclides ^{40}K, ^{232}Th and ^{238}U and their decay products with high heterogeneity depending on the geology of the location. Radon (^{222}Rn) and its isotope thoron (^{220}Rn) are two gaseous radionuclides produced in the ^{238}U and ^{232}Th radioactive decay series respectively. These two airborne radionuclides and their progeny are responsible for the inhalation radiation dose to the human beings.

Radon is the only radioactive gas in the decay chain of uranium found naturally in soil, rock and water. Being chemically inert gases, both radon and thoron migrate easily from ground to the indoor and outdoor atmosphere mainly through a pressure driven mechanism. When it happens to accumulate to high concentrations, in the enclosures like rooms with poor ventilation, they become a cause of higher health concern for the inhabitants in such rooms.

Radon is the most important cause of lung cancer after smoking, accounting for 3–14% of all lung cancer [1]. The lower the radon exposure, the lower the lung cancer risk as no known threshold below which radon causes risk. Epidemiological researches in Europe, North America and China have confirmed that even low concentrations of indoor radon contribute significantly to the occurrence of lung cancers worldwide. In United States, nearly one home out of fifteen homes are known to have high radon levels and lung cancer mortality numbers more than 20,000 per annum very close to the incidences of Lymphoma and Leukemia [2]. The alpha decays of ^{218}Po and ^{214}Po radio isotopes, in ^{222}Rn series, ^{212}Bi and ^{212}Po in ^{220}Rn series impart the highest radiation dose to the basal cells in the upper bronchial tree of the human lungs [3].

Subsoil emanation, building materials and underground water are the principal sources of this inert radioactive gas in the indoor atmosphere. Radon and thoron gases find their way from soil gas to indoor environment through the floors, cracks in walls, joints in the construction, floor drains, ground water and building materials. Outdoors, radon quickly dilutes to very low concentrations. Radon escapes easily from the ground into the air, where it decays and produces further radioactive particles. As we breathe in, the particles are deposited on the cells coating the airways, where they can damage DNA and can ultimately result in lung cancer. Several countries encourage mitigation strategies decelerating entry of radon inside the rooms through proper choice of building materials, use of sealants, improving ventilation, suitable construction designs and sub-floor depressurization.

Papua New Guinea (PNG) is a south-western pacific country with vast resources of minerals, metals, oil and gas. There are nearly two dozens of active mining cites in the country. All mining activities fetch the crustal materials of earth to the surface of earth relocating the radionuclides to the biosphere resulting in enhanced level of natural radioactivity. Presence of excess levels of radioactive minerals and isotopes in soil and environment may result in higher radiation exposure to the human beings. Even with several mining industrial activities in various parts of the country, no comprehensive assessment of natural environmental radioactivity has been reported to have carried out in PNG. Occurrence of oral cancer is highest in PNG among Asia and Oceania region along with the cases of cervix, breast and lung carcinoma.

The principal component of total radiation exposure to the general public is the exposure to natural background radiation. Of all the radiation exposure to human beings, inhalation radiation dose tops the table with a lion share of about 55% [4]. The present study was an initiative to assess the indoor radon, thoron and their progeny levels in selected locations of the second largest city of Lae in PNG. We have also made an attempt to assess the flux rate of radon gas from soil air to the atmosphere in one of the locations of study.

II. Methodology

The locations for the study were selected from the

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residential areas of the Lae city and also from the housing areas of PNG University of Technology. Concentrations of indoor radon, thoron and their progeny vary widely with ventilation of the room, wind speed, type of house, building materials, humidity, pressure and temperature [5]. Hence long term integrated methods are best suited for obtaining statistically acceptable representative results.

10 locations in different parts of Lae city in the Morobe Province of Papua New Guinea was selected for the studies. In all the ten locations dwellings with normal living conditions without air-conditioning were selected for the study. All the houses were typical Papua New Guinean homes constructed to withstand frequent tremors in the region.

A. Radon and Thoron Measurements

For the present study, we employed both active and passive methods of measurement of indoor radon concentration. Thoron and progeny levels were determined through the long term passive measurements only.

B. Active Measurement

Active measurements were carried out in the houses with a digital radon measuring device (Corentium, Norway) which is can measure indoor radon averaged over 24 hours or for a longer period. The device is also capable of reading out instant and cumulative inhalation dose. However, the results of active measurements were used only as a mode for validation of data obtained from long term passive measurements.

C. Passive Measurements

For radon detection and inhalation dosimetry through passive time integrated method, most widely used modern technique is dielectric detector based diffusion cup. In our study we have employed the single entry pin-hole twin cup dosimeters for the estimation of radon and thoron concentrations in the indoor atmosphere [6]. A schematic diagram of the single entry pin-hole twin cup dosimeters is shown in figure 1(a).

D. Radon and Thoron Progeny Measurements

For precise inhalation dose assessments, we need to know the equilibrium status of radon and thoron gases in the indoor atmosphere. Therefore, we carried out simultaneous measurements of radon and thoron progeny levels inside the dwellings in all the locations using the Direct Radon Progeny Sensor (DRPS) and Direct Thoron Progeny Sensor (DTPS).

The basic principle of the DRPS and DTPS is the selective detection of alpha particles originating from ^{214}Po of radon progeny and ^{212}Po of thoron progeny, which are deposited on the surface of the absorber kept on the detector film. The absorber in DRPS is a combination of 25 µm aluminum mylar and 12 µm cellulose nitrate peeled off from LR115 detector. It records tracks of alpha particles emitted from both ^{214}Po of energy 7.69 MeV and ^{212}Po of energy 8.78 MeV. Whereas DTPS absorber is a 50 µm aluminum Mylar, which permits only the alpha particles of energy 8.78MeV emitted from ^{212}Po to pass through it to be recorded in the detector film. Therefore, from the track densities recorded in the detector films, radon and thoron progeny concentrations are determined. This is a method largely accepted for the passive determination of progeny levels. [7], [8].

E. Radon Exhalation Rate Measurements

While measuring the indoor radon levels in a region, it is worthwhile to assess the rate of exhalation of the gas from the surface soil in the same region. This would help the researcher to make out the extend of effective delivery of radon from soil air to the indoor and outdoor environment. The most common approach for determining radon exhalation rate from soil is the accumulator method in which soil air containing radon is allowed to diffuse into an accumulator chamber to reach a steady state. A schematic diagram of the radon accumulator for determining radon exhalation rate is shown in figure 1(b). The measuring device records the radon activity with time. The radon growth equation in a typical accumulator is represented by the exponential relation [9], [10].

$$C(t) = C_o e^{-\lambda_e t} + \frac{J_S A}{V \lambda_e}\left(1 - e^{-\lambda_e t}\right) \quad (1)$$

where C_o is the initial (t = 0) radon concentration inside the accumulator, $C(t)$ is radon concentration (Bq m^{-3}) at any time, J_s is the rate of radon exhalation from soil (Bq m^{-2} h^{-1}), V is volume of the accumulator (m^3), λ_e is the effective decay constant (h^{-1}) of radon for the given set up which is the sum of radon decay constant, leakage rates and back diffusion rate for the set up and A is the area of soil surface covered by accumulator (m^2). Using radon concentrations at different intervals, we can obtain the effective decay constant, λ_e. At steady state condition the equation (1) reduces to the following equation using which we can estimate the exhalation rate.

$$J_s = \frac{C_O V \lambda_e}{A} \quad (2)$$

III. Experimental

A. Measurement of Radon and Thoron Concentrations

Single entry pin-hole twin cup dosimeters were used for the estimation of time averaged concentrations of radon and thoron in the indoor atmosphere. The dosimeter has two identical cylindrical chambers of length 4.1cm and diameter 6.2cm separated by a central disc with four pinholes. Radon and thoron gases from the indoor air diffuse into the first 'radon + thoron' chamber of the dosimeter through a glass fibre filter paper of thickness 700 µm. The filter paper prevents the entry of all solid particles including radon and thoron progeny into the first chamber of the dosimeter. The central disc has four pin-holes of 0.2 cm length and 0.1 cm diameter, which help to prevent the diffusion of short lived thoron into the inner second chamber. This helps to discriminate radon from thoron by acting as a diffusion barrier for short-lived (half-life of 55.6s) thoron. Thus only radon enters into the second chamber called 'radon only chamber' [11].

LR115-Type II is manufactured by Kodak Pathe, France. The LR-115-Type II pelliculable, alpha sensitive films of 3 x 3 cm^2 size were fixed in both chambers of the dosimeter. Alpha particles emitted from radon and thoron register nuclear tracks in the LR115 detector fixed in the first (radon+thoron) chamber, while the LR115 detector in second (radon only) chamber records tracks from the alpha particles emitted by radon in the chamber.

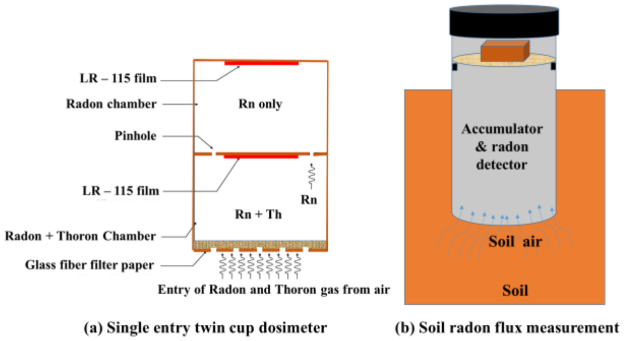

Fig. 1. Schematic diagram (not to the scale) of twin cup dosimeter and radon flux accumulator.

In the selected 10 locations, altogether 60 detectors were exposed for about three months inside the rooms in a phased manner. The dosimeters were suspended in the indoor environment at the height of about 1.5 meters from the floor of the room. Corners were avoided so that the detectors are not exposed to two exhaling surfaces. After about three months' exposure, the dosimeters were retrieved for analysis. The LR 115 films were chemically etched to develop the alpha tracks and the sensitive part of the films were peeled off to scan using a spark counter to obtain the track densities on each film. After several scanning, the average track densities were converted to radon and thoron concentration using the predetermined calibration factors. [11].

B. Measurement of Radon and Thoron Progeny

Each DRPS and DTPS has two sets of detectors fixed with them for obtaining statistically superior results. While fixing pinhole dosimeters at dwellings, DRPS and DTPS were also exposed in the indoor environment. After exposure, these detector films were also chemically etched and scanned to determine the track densities on them. The equilibrium equivalent decay product concentrations were estimated from the track densities using the sensitivity factors obtained from calibration experiments [7]. The tracks registered in DTPS are entirely due to thoron progeny, and that can be directly used to calculate equilibrium equivalent thoron concentration (EETC). But in DRPS, both and radon and thoron progenies register tracks. So it is necessary to deduce the track density of thoron progeny estimated from the DTPS using the following equation (3) [8].

Track density due to Rn progeny = Total track density on

$$\text{DRPS} - \frac{\eta_{RT}}{\eta_{TT}} \text{Track density on DTPS} \quad (3)$$

Here, η_{RT} = 0.083, which is the track registration efficiency of thoron progeny in DRPS and η_{TT} = 0.01, track registration efficiency of thoron in DTPS

The equilibrium equivalent ^{222}Rn progeny (EERC) and ^{220}Rn progeny (EETC) concentrations were calculated using the formulae (4) and (5):

$$\text{EETC (Bqm}^{-3}) = \frac{\text{Track density on DTPS}}{K_T \times \text{Exposure time}} \quad (4)$$

$$\text{EERC(Bqm}^{-3}) = \frac{\text{Track density only due to radon progeny}}{K_R \times \text{Exposure time}} \quad (5)$$

where K_T and K_R are the calibration factors for DTPS and DRPS, respectively. The values adopted in this assessment were 0.94 Tracks cm^{-2} d^{-1}/EETC (Bqm^{-3}) for DTPS and 0.09 Tracks cm^{-2} d^{-1}/EERC (Bqm^{-3}) for DRPS [8].

C. Soil Radon Exhalation Measurement

For the measurement of principal source term, the exhalation rate of radon, we used active method of determination of radon emanated directly from soil. A cylindrical accumulator of length 50cm and radius 7cm made of 0.5cm thick PVC with an airtight lid was used. The open end of the accumulator was exposed to the soil air with about 25 cm length below ground level. At the top of the accumulator, the digital continuous radon detector was fixed. The device was set to record radon activity for short term as well as long term average of total exposure. Using the radon activity data radon exhalation rate was determined using the equation (2).

D. Inhalation Dose Due to Radon, Thoron and Progeny Exposure

The total annual inhalation dose from the exposure to radon, thoron and their progeny was calculated using the equation (6) employing dose conversion factors provided by UNSCEAR (2000) [4].

$$\text{Dose (mSv y}^{-1}) = 8760 \times 0.8 \times 10^{-6} \times [(0.17 + 9 \times F_R)\, C_R + (0.11 + 40 \times F_T)\, C_T\,] \quad (6)$$

where, F_R and F_T are the equilibrium factors of radon and thoron progeny respectively. C_R and C_T are the radon and thoron concentration in Bq m^{-3}, respectively. Indoor occupancy factor was taken as 0.8 and the numerical quantities 0.11 and 40 are the dose conversion factors for thoron and its progeny while 0.17 and 9 are the dose conversion factors for radon and its progeny [4].

IV. Results and Discussion

Average radon and thoron gas concentrations in the indoor atmosphere in 10 locations are presented in the table 1. The radon concentration was found to vary from 8.40 to 18.1 Bq m^{-3} with arithmetic mean 13.4±3 Bq m^{-3}. Thoron concentration was found to be quite low with a mean of 2.5±1 Bq m^{-3}. Equilibrium factor between radon and progeny was found vary widely from 0.14 to 0.49 with a mean of 0.28±0.13. Similarly, for thoron and progeny, equilibrium factor was found to vary from 0.005 to 0.027 resulting in an average of 0.014±0.007. The most important factor of radiological concern, the annual inhalation dose resulting from radon, thoron and their progeny varied from 0.16 to 0.55 mSv with the average 0.25±0.12 mSv. The spatial variation of the inhalation dose in the Lae city has been presented in the Fig. 2.

Indoor radon and thoron concentrations vary very widely depending on several factors all over the world. The global average of radon concentration is 40 Bqm^{-3} and that for thoron is 10 Bqm^{-3} [5].

The levels of radon as well as thoron in the dwellings are found to be much low in the dwelling of Lae. This is attributable to the typical style of constructions of the houses in the region. PNG is situated in the volcanic and earthquake prone region of 'ring of fire' in the pacific. Therefore, the houses are mostly made on pillars to resist the frequent tremors.

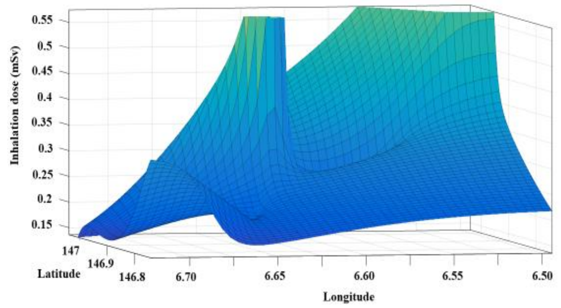

Fig. 2. Profile of annual inhalation dose in the locations.

Therefore, the possibility for accumulation of radon or thoron gas underneath the dwellings is very rare. The tropical weather conditions give ample chance for good ventilation and thereby dilution of indoor air. The common building materials used in the region may also not contributing much to the indoor radon or thoron.

According to UNSCEAR (2006), the global average of equilibrium factor of radon is 0.4 and that for thoron is 0.02 [12]. Equilibrium factors obtained for Lae are lower for both radon and thoron. This can also be attributed to good ventilation conditions of the dwellings allowing the progeny to get diluted and cleared off the indoor environment.

Radon flux rate estimate made with saturated radon concentration in the chamber, 3566±950 Bq m^{-3}, and the effective decay constant of 7.56×10^{-3} h^{-1} (= 2.1×10^{-6} s^{-1}) was 13.48±3.6 Bq m^{-2} h^{-1}. The soil radon activity as well as the flux to the atmosphere are comparable with the figures reported in the literature for other regions [13].

The world average annual inhalation dose due to radon, thoron and their progeny have been reported to be in the range of 2 to 10mSv [14]. The estimated inhalation dose to the inhabitants of dwellings in Lae was found to be much less.

TABLE I: ESTIMATED AVERAGE CONCENTRATIONS OF RADON, THORON, EQUILIBRIUM EQUIVALENT PROGENY CONCENTRATIONS (EERC AND EETC), EQUILIBRIUM FACTOR (EF) FOR RADON AND THORON AND TOTAL INHALATION DOSE TO THE INHABITANTS IN THE LAE CITY IN PNG

Locations	Rn (Bqm^{-3})	EERC (Bqm^{-3})	EF Rn	Tn (Bqm^{-3})	EETC (Bqm^{-3})	EF Tn	Total Inhalation dose ($mSvy^{-1}$)
1	8.40	2.5	0.30	3.5	0.024	0.007	0.18
2	14.3	2.8	0.20	2.9	0.048	0.016	0.21
3	12.7	3.2	0.25	4.1	0.022	0.005	0.23
4	18.1	3.5	0.19	1.2	0.020	0.017	0.25
5	14.5	2.1	0.14	2.5	0.020	0.008	0.16
6	14.4	3.8	0.26	1.8	0.048	0.027	0.27
7	12.4	2.5	0.20	2.9	0.066	0.022	0.19
8	12.6	2.4	0.19	2.9	0.026	0.009	0.17
9	17.3	8.4	0.49	0.7	0.011	0.015	0.55
10	9.50	5.0	0.52	1.9	0.023	0.012	0.33
Mean	**13.4**	**3.6**	**0.28**	**2.5**	**0.031**	**0.014**	**0.25**
Std Dev	**3.0**	**1.9**	**0.13**	**1.1**	**0.017**	**0.007**	**0.12**

The quantitative analysis of radon and thoron data using QQ plot of the logarithm of radon and thoron concentrations for all the dwellings is shown in Figure 3. There is only limited linearity seen in the plots. Hence they do not confirm lognormal distribution of radon and thoron concentrations in the city of Lae.

There are several observations of lognormal distributions of indoor radon concentrations in many studies. Mostly those regions were reported to have more or less homogeneous sources of radon and thoron gases. In that sense, either the sources and/or the pathways of radon in the present area of study ought to be highly heterogeneous.

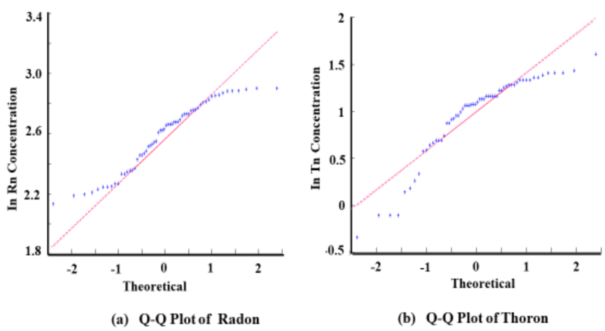

Fig. 3. The QQ plot of the distribution of radon (a) and thoron (b) in the dwellings.

V. CONCLUSIONS

The preliminary study conducted in the Lae city in PNG indicate that, in spite of the radon activity in the soil air and the flux to the atmosphere are comparable with other countries and places, indoor activity of radon, thoron and their progeny are considerably meagre. Unlike most of other countries, pressure driven radon entry into the indoor environment through the floor of dwellings and/or the contribution of the building materials could be negligible due to the construction style and materials used for fabrications. The quantile analysis indicates a heterogeneous distribution of radon gas which is attributable to the varying radionuclide concentrations in the soil. Detailed study of the radioactive contents of the soil, mechanism of radon entry and dilution to the environment are necessary for confirmative conclusions.

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